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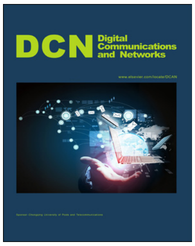

A vision-based terrain morphology estimation model inspired by the avian hippocampus

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Abstract
Homing pigeons are known for their ability to return home after being released from a location spanning up to hundreds of miles. They make use of detected visual features in the environment, the earth's magnetic field as well as using the hippocampus region of the brain to construct spatial maps of the environment. This is unlike present day UAVs that rely on GPS and radio/satellite communications with a ground station, both of which might not be available during a major disaster scenario such as a solar flare.

In this paper, we take inspiration from the avian hippocampus and develop a preliminary model for estimating a terrain's morphology using visually detected features on the terrain. This could then be used to localise a portable micro-UAV during a demining task for humanitarian purposes in third world countries affected by buried land mines from previous wars. Our goal is that in future, the presented model and algorithm in this work would enable effective coverage of an affected area using the visual information obtained from the environment.

1. Introduction

Land mines are hidden dangers that result in over 20,000 injuries or fatalities every year [1]. In third world countries affected by forgotten land mines, a technique that can (i) reliably cover a region of interest, (ii) effectively detect mines, (iii) be reusable after each mission (iv), used by the natives of the region with very little training, and (v) be cheaply maintained using off the shelf components would be beneficial. We propose the use of an autonomous portable microUnmanned Aerial Vehicle ($p\mu UAV$) system for mine detection and visualisation. This is unlike previous approaches, that make use of metallic detectors [2,3], trained animals [4] and ground-penetrating radar [5]. These previous techniques are either expensive or not readily accessible by untrained people. Furthermore, most autonomous techniques make use of ground robots [1,6] which are susceptible to damage upon contact with a buried landmine.

A $p\mu UAV$ can be reused many times with minimal risk of destruction due to minimal contact with the ground. Upon detection of a mine, the $p\mu UAV$ would spray a cheap locally

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sourced paint on the spot where the mine has been detected. This would serve as a visual indication of where to avoid on a contaminated land. In order to achieve this however, the *pμUAV* must be capable of autonomous navigation and localisation in the environment within which it is deployed as well as return autonomously to its user after a mission. To achieve this capability, we take inspiration from the homing pigeon.

Homing pigeons are known for their ability in returning home after being released from a location spanning up to hundreds of miles. They are guided by features detected in the environment using their vision, the earth's magnetic field using the biological equivalent of a magnetic compass and by using the hippocampus region of the brain to construct spatial maps of the environment. This ability has not yet been achieved by present day UAVs. Present day UAVs rely on GPS for waypoint navigation as well as localisation. However, current GPS technologies are not yet advanced enough to provide precise localisation information to a *pμUAV* for use on a patch of land the size of football pitch. The drift associated with the GPS signals would lead to uncovered areas of land. Furthermore, GPS signals could be affected by surrounding tall structures or by a natural disaster such as a solar flare.

However, our proposed approach aims to enable a *pμUAV* navigate using detected environmental features and return to the user for safe retrieval after a mission. In this paper, we focus on detecting visual features on a terrain of interest and then computationally reconstructing the terrain towards future terrain-based navigation. The main contributions of this paper are (i) a preliminary software architecture based upon the pigeon hippocampus; (ii) terrain morphology estimation and terrain map building using visually detected features and (iii) an adapted self-organising neural network. The rest of this paper is organised as follows: Section 2 presents a brief literature review about the support in the role of the hippocampus for building and storing maps followed by Section 3 where we present our model for use in our work with experimental results. We conclude this paper in Section 4 with a brief discussion and future work.

2. Support of the hippocampus in map building

The hippocampus is a section in the brain that has been implicated in the formation and storing of spatial memory [7,8]. This brain section enables multi-cellular organisms such as mammals, primates, and birds to explore their environment, know their location in the environment and then subsequently find their way home during foraging trips.

There is evidence to suggest that the more exploration of an environment an organism does, the greater the volume of its hippocampus [7,11,12]. In [7] for example, black cab taxi drivers were observed to have larger hippocampus than the average human. This is due to the training requirement of memorising road networks in London in order to ferry passengers from one location to another. It has also been proven through experiments that more experienced birds tend to have a larger hippocampus than the less experienced birds [9]. This could be because of the need to store a larger amount of spatial cues obtained from the environment [9,10].

It can be hypothesised that environmental pressures and how the environment is used play a part in the differences between various organisms hippocampus. For example, since the Rat's environment is made up of tunnels, corridors and mazes, its hippocampus would have evolved for this type of environment while that of the Pigeon would be more suited for free range flying environments. This is hypothesis is supported by [9,11] that discuss how the hippocampus is functionally similar between the avian and mammalian hippocampus but different in what information is stored as well as how it is stored and encoded.

In rats for example, it has been discovered that a specific set of neurons in the hippocampus fire when the rat is at a particular location containing a set of visual features. This gave them the name place cells [13]. In food gathering birds however, it was found out that these place cells were more connected to the location of food patches in the environment. It has been hypothesise that these food cells apart from storing the content and amount of food kept in holes in the environment, are also used to memorise the visual features of landmarks in the vicinity of the food store [8,9]. This also seems to suggest that Pigeons rely on visual landmark features to navigate and localise themselves in the environment [14].

Adapting the above observations to robotics, it can be hypothesised that: (i) the memory requirements of a robot will be proportional to the size of the environment it will be operating in and the quantity of features/spatial cues in that environment. This knowledge was used to determine the size of the neural network to use for navigation and localisation in the next section; (ii) prominent visual features can be used to detect and localise very important (food patches in the case of birds) locations in the environment; (iii) prominent visual features can be used as triggers to store and encode data relating to that visual feature. The type of data stored can be dependent on application. Data stored could be terrain height at a particular location, colour, texture and so on. In this work, we focused on estimating and storing terrain morphology. In future, this will be extended to store the locations of buried mines as well.

3. Developing a computational model of the pigeon hippocampus for the demining *pμUAV*

Attractor dynamics neural network with global inhibition is often used to model the hippocampus as in the RatSLAM [15] and in the BatSLAM [16]. These two SLAM techniques are based on the mammalian hippocampus. Even though Stringer et al. [17] also used it in studying various models of the hippocampus, Stella et al. argued that attractor dynamics is not only unique to the hippocampus but can also be found in other areas of the brain [11]. In this work, a self-organising network is proposed to be used as a tool to simulate the hippocampus. The network would be used for the purposes of storing memories or maps of the terrain to be investigated. According to present knowledge, this theory has never been used to simulate the hippocampus.